Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 1 February 2008 (MN LaTeX style file v2.2)

PSR J1453+1902 and the radio luminosities of solitary versus binary millisecond pulsars

D.R. Lorimer[1],* M.A. McLaughlin[1], D.J. Champion[2] and I.H. Stairs[3]
[1] *Department of Physics, West Virginia University, PO Box 6315, Morgantown, WV 26506, USA*
[2] *McGill University Physics Department, Montreal, QC H3A2T8, Canada*
[3] *Department of Physics & Astronomy, University of British Columbia, 6224 Agricultural Road, Vancouver, B.C. V6T 1Z1, Canada*

Accepted 2007 May 4. Received 2007 May 3; in original form 2007 April 15

ABSTRACT
We present 3 yr of timing observations for PSR J1453+1902, a 5.79-ms pulsar discovered during a 430-MHz drift-scan survey with the Arecibo telescope. Our observations show that PSR J1453+1902 is solitary and has a proper motion of 8 ± 2 mas yr^{-1}. At the nominal distance of 1.2 kpc estimated from the pulsar's dispersion measure, this corresponds to a transverse speed of 46 ± 11 km s^{-1}, typical of the millisecond pulsar population. We analyse the current sample of 55 millisecond pulsars in the Galactic disk and revisit the question of whether the luminosities of isolated millisecond pulsars are different from their binary counterparts. We demonstrate that the apparent differences in the luminosity distributions seen in samples selected from 430-MHz surveys can be explained by small-number statistics and observational selection biases. An examination of the sample from 1400-MHz surveys shows no differences in the distributions. The simplest conclusion from the current data is that the spin, kinematic, spatial and luminosity distributions of isolated and binary millisecond pulsars are consistent with a single homogeneous population.

Key words: pulsars: general — pulsars: individual — PSR J1453+1902

1 INTRODUCTION

Twenty-five years after the discovery of the first millisecond pulsar (Backer et al. 1982), the sample of these objects currently known is now close to 200, with the majority being found in searches of globular clusters (for a review, see Camilo & Rasio 2005). While searches in clusters are far from straightforward, finding millisecond pulsars in the Galactic disk is a difficult endeavour due to the dispersive and scattering effects of the interstellar medium which hamper their detection. Indeed, only 55 out of roughly 1500 pulsars (4%) currently known in the Galactic disk are millisecond pulsars. Despite this low fraction, the numbers are now at the level where statistically significant trends can be identified in the sample and inferences made about the underlying population.

One such example is the apparent difference in luminosities between isolated and binary millisecond pulsars, first noted by Bailes et al. (1997) from 430-MHz observations, in which isolated millisecond pulsars were on average fainter than their binary counterparts. This trend was also seen by Kramer et al. (1998) in 1400-MHz data. More recently, Lommen et al. (2006) revisited this issue from a different perspective. They found that, while the velocity distribution of the isolated millisecond pulsars is compatible with that of binary systems, there appears to be a difference in the distribution of heights above the Galactic plane for the two populations, with solitary millisecond pulsars residing closer to the plane than the binary systems. As discussed by Lommen et al. (2006), given identical velocity dispersions, the only way to explain the different scale heights would be if the isolated millisecond pulsars are truly fainter on average and therefore harder to detect further from the Earth and hence closer to the Galactic plane. If the luminosity difference is a real effect, then it represents an important clue to the origin of millisecond pulsars.

To increase the sample of millisecond and binary pulsars in the Galactic disk, we have been carrying out drift-scan surveys with the Arecibo telescope (Lorimer et al. 2004; Champion et al. 2005; McLaughlin et al. 2005; Lorimer et al. 2005). Two isolated millisecond pulsars were found in this survey: PSR J1944+0907 (Champion et al. 2005) and PSR J1453+1902 which was briefly discussed by McLaughlin et al. (2005). In this paper, we present the discovery and detailed follow-up observations of PSR J1453+1902 and take the opportunity to compare what is currently known about the population of solitary and binary millisecond pulsars. In Section 2 we describe

* Email: Duncan.Lorimer@mail.wvu.edu

our observations and present a timing ephemeris for PSR J1453+1902. As shown in Section 3, these timing measurements rule out the presence of any Earth-mass companions around this pulsar. In Section 4, we carry out a comparison of the solitary and millisecond pulsar samples. Our conclusions are summarized in Section 5.

2 DISCOVERY AND TIMING OF PSR J1453+1902

The 5.79-ms pulsar J1453+1902 was one of eleven pulsars found during a 430-MHz survey with the Arecibo telescope (McLaughlin et al. 2003; Lorimer et al. 2004; McLaughlin et al. 2005). The survey observations were carried out in drift-scan mode using the Penn State Pulsar Machine (PSPM), a 128×60-kHz channel analogue spectrometer, to acquire radio signals from the 430-MHz line feed at Arecibo with 4-bit precision every 80μs. After combination of the two orthogonal circular polarizations, total-power data were written to tape for off-line processing. In this mode, a point on the sky drifted through the 10-arcmin primary beam in about 40 s and data were collected along strips of constant declination δ at a rate of 60 $\cos\delta$ deg^2 per day. Roughly 1700 deg^2 of sky was covered during the survey.

The data were subsequently searched for periodic and transient events off-line using freely-available analysis tools[1] following the procedure described by Lorimer et al. (2004). PSR J1453+1902 was originally detected at a dispersion measure (DM) of 14.2 cm^{-3} pc with a signal-to-noise ratio of 27 in the amplitude spectrum of the Fourier transform from data taken on 1998, January 19. Follow-up timing observations were carried out on all the pulsars from the survey using the 430-MHz Gregorian receiver at Arecibo and the PSPM as described in detail by Champion et al. (2005). For PSR J1453+1902, all data were taken in search mode and folded off-line using a preliminary ephemeris derived from the original search detection. Pulse time-of-arrival (TOA) measurements were obtained from the folded data by convolving each integrated profile with a high signal-to-noise template formed from many independent observations (for further details on the timing procedure, see, e.g., Lorimer & Kramer 2005). The final template used in the analysis is shown in Fig. 1. As seen in some other millisecond pulsars, (see, e.g., Kramer et al. 1998), the pulse shape is complex with significant amounts of emission over most of the pulse.

A typical observing session consisted of several 10-min observations of the pulsar. These profiles were subsequently phase-aligned using an interim timing model to form a single daily profile. A phase-coherent timing observation was finally obtained from 62 TOAs spanning a three-year period (MJD range 52768–53905) using the TEMPO2 software package[2] (Hobbs et al. 2006). This process yields an excellent fit to the TOAs using seven free parameters: right ascension (α), declination (δ), proper motion in right ascension (μ_α), proper motion in declination (μ_δ), spin period (P), period

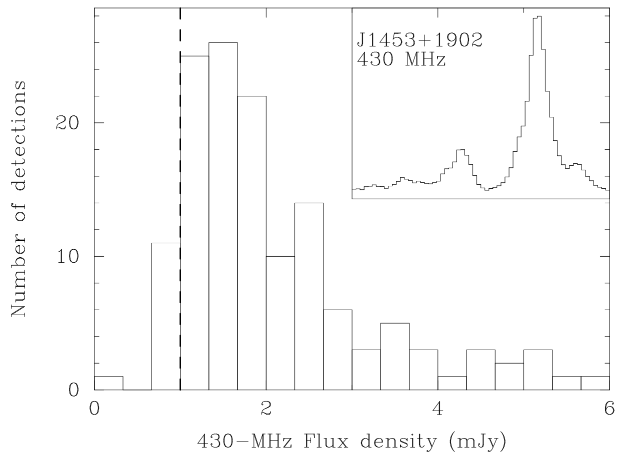

Figure 1. Distribution of 430-MHz flux densities for PSR J1453+1902. The dashed line shows the detection threshold for this pulsar in our original search-mode observation. Inset: integrated 430-MHz profile showing 360 degrees of rotational phase. The profile was produced by phase-aligning and summing all the 430-MHz detections. The equivalent integration time is 39.3 hr and effective time resolution (calculated from the quadrature sum of the 80 μs sampling time and the dispersive smearing across a 60-kHz PSPM frequency channel) is 149 μs.

derivative ($\dot{P}$) as well as an arbitrary pulse phase shift. To account for unknown systematic effects, individual TOA uncertainties were multiplied by a factor of 1.7 to ensure a reduced χ^2 value of unity. The resulting model minus computed post-fit weighted residuals were free from systematic trends with a root-mean-square value of 5.2 μs. The parameter values and their uncertainties are given in Table 1. The equivalent position in Galactic longitude and latitude (l and b) and the composite proper motion ($\mu = \sqrt{\mu_\alpha^2 + \mu_\delta^2}$) are also listed. The dispersion measure (DM) was obtained in a subsequent call to TEMPO2 in which the nominal best-fit parameters from the previous fit were held constant and TOAs derived from four independent sub-bands across the 7.68 MHz PSPM band were used in the fit.

For each 10-min observation, we estimated the flux density of PSR J1453+1902 by measuring the off-pulse DC level of the dedispersed profile (D) before it was subtracted. Following Lorimer et al. (2002), the resulting profile was converted into mJy units via the scaling factor $1000\,T/(DG)$, where T is the system temperature and G is the receiver gain. In these calculations, we assumed a 55 K receiver temperature plus an additional contribution of 33 K from the sky background and $G = 10$ K Jy^{-1} for the Gregorian system.[3] As can be seen from the distribution of flux densities shown in Fig. 1, the flux density varies from the mean value of 2.2 mJy by a factor of 2–3. This is consistent with the modulation from diffractive scintillation in the interstellar medium. Given the distribution of flux densities we observe, PSR J1453+1902 is above the approximate 1-mJy survey flux density threshold about 90% of the time. Although the pulsar is a relatively weak object, its high Galactic latitude and large angular offset in the sky from other millisecond

[1] http://sigproc.sourceforge.net
[2] http://www.atnf.csiro.au/research/pulsar/tempo2

[3] Technical details of the receivers at Arecibo can be found at http://www.naic.edu/~astro/RXstatus.

Table 1. Observed and derived parameters for PSR J1453+1902

Parameter	Value
Right ascension, α (h:m:s) (J2000)	14:53:45.7175(1)
Declination, δ (deg:m:s) (J2000)	19:02:12.224(3)
Proper motion in α, μ_α (mas yr^{-1})	3.2(12)
Proper motion in δ, μ_δ (mas yr^{-1})	–6.8(24)
Spin period, P (ms)	5.7923027349664(4)
Epoch of period (MJD)	53337.0
Period derivative, $\dot{P}$ ($\times 10^{-20}$ s s^{-1})	1.162(3)
Dispersion measure, DM (cm^{-3} pc)	14.049(4)
430-MHz flux density, S_{430} (mJy)	2.2(1)
Galactic longitude, l (deg)	23.395
Galactic latitude, b (deg)	60.812
50% pulse width, w_{50} (ms)	0.4
10% pulse width, w_{10} (ms)	1.1
Composite proper motion, μ (mas yr^{-1})	8(2)
DM-derived distance, d (kpc)	1.2
Height above the Galactic plane, z (kpc)	1.0
430-MHz luminosity, L_{430} (mJy kpc^2)	3.2
Transverse speed, v_t (km s^{-1})	46(11)
Kinematic bias to $\dot{P}$, $\dot{P}_{\rm kin}$ ($\times 10^{-20}$ s s^{-1})	0.11
Characteristic age, τ (Gyr)	8.0
Magnetic field strength, B (10^8 G)	2.5
Spin-down luminosity, $\dot{E}$ (10^{33} ergs/s)	2.1

The numbers in parentheses are twice the quoted uncertainties from TEMPO2 and represent approximately 1-σ uncertainties in the measured parameters. Note that TEMPO2 was invoked with the `-tempo1` option so that the quoted timing parameters are in barycentric dynamical time units.

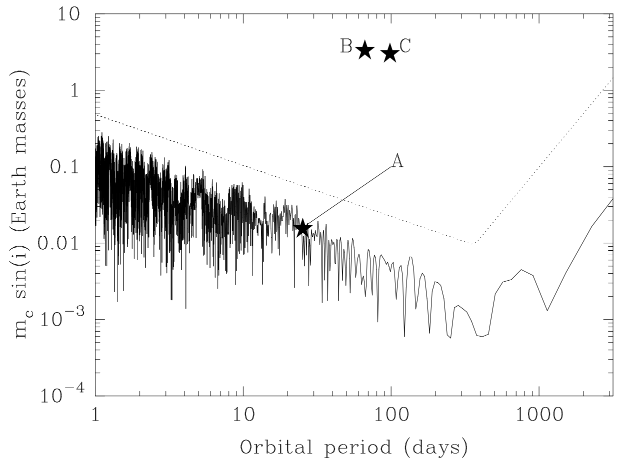

Figure 2. Lomb-Scargle spectrum for the timing residuals of PSR J1453+1902 shown as a function of companion mass versus orbital period. For details of the calculation, see Freire et al. (2003). The dotted line shows the 99.9% confidence level of the analysis. All features in the spectrum are well below this limit, indicating that there are no significant periodicities in the data. For comparison, the starred points show the three planets (A, B and C) in the PSR B1257+12 system.

pulsars may make it an important addition to the millisecond pulsar timing array (see, e.g., Jenet et al. 2006).

Also listed in Table 1 are several derived parameters: the distance to the pulsar in kpc (d) estimated from the DM using the Galactic electron density model of Cordes & Lazio (2002), the height above the Galactic plane ($z = d \sin b$) and 430-MHz luminosity $L_{430} = S_{430} d^2$. Using the distance estimate and proper motion measurement, we infer the transverse speed $v_t = \mu d = 46 \pm 11$ km s^{-1}, typical of the millisecond pulsar population (see, e.g., Hobbs et al. 2005). The proper motion and distance allow us to calculate the kinematic contribution to the observed $\dot{P}$ (Shklovskii 1970) via $\dot{P}_{\rm kin} = \mu^2 dP/c$. This amounts to a 10% overestimate of the true $\dot{P}$ value and we take this into account when calculating the characteristic age ($\tau = P/2\dot{P}$), inferred surface dipole magnetic field strength ($B = 3.2 \times 10^{19}\sqrt{P\dot{P}}$ Gauss) and spin-down luminosity ($\dot{E} = 3.95 \times 10^{46} \dot{P}/P^3$ ergs s^{-1}). For further details of the definitions and assumptions in these parameters, see, e.g., Lorimer & Kramer (2005).

3 A SEARCH FOR ORBITING COMPANIONS

An interesting issue ever since the discovery of planets around PSR B1257+12 (Wolszczan & Frail 1992) is the lack of any other millisecond pulsar planetary system in the Galactic disk. The rarity of such planets makes it important to place limits on newly found millisecond pulsars by searching for periodic signals in the timing residuals. Following the procedure described in detail by Freire et al. (2003), we have carried out a Lomb-Scargle periodogram analysis (Press et al. 1986) on the timing residuals for PSR J1453+1902. Although we found no significant periodicities in the data, ruling out all Earth-mass planets, as shown in Fig. 2 we cannot presently exclude smaller bodies, such as the 0.02 $M_\oplus$ planet A in the B1257+12 system.

We have carried out a similar analysis on the timing residuals from the other solitary 5.2-ms pulsar from this survey, PSR J1944+0907 (Champion et al. 2005). These data are of similar quality and also reveal no significant signals. Planetary systems around pulsars remain a very rare phenomenon.

4 MILLISECOND PULSAR STATISTICS

PSR J1453+1902 brings the total number of solitary millisecond pulsars in the Galactic disk to 17. Given the larger sample size available to us than in the past (Bailes et al. 1997; Kramer et al. 1998), it is appropriate to revisit the question of whether there is a difference between the luminosities of isolated and binary millisecond pulsars. As mentioned in Section 1, Lommen et al. (2006) have recently compared the velocity distributions of 9 solitary millisecond pulsars and 20 binary millisecond pulsars and find them to be consistent. Surprisingly, however, they also find evidence for a smaller z height distribution in the isolated pulsar population. Given the identical velocity distributions, this could be explained by a difference in luminosity between the two populations.

We have carried out an updated census of the binary and solitary millisecond pulsar populations with a view to assessing the significance of the luminosity distribution difference. We therefore compiled a catalogue of flux density and distance measurements for all currently known millisecond pulsars in the Galactic disk with $P <$ 10 ms. We excluded the millisecond pulsar planetary sys-

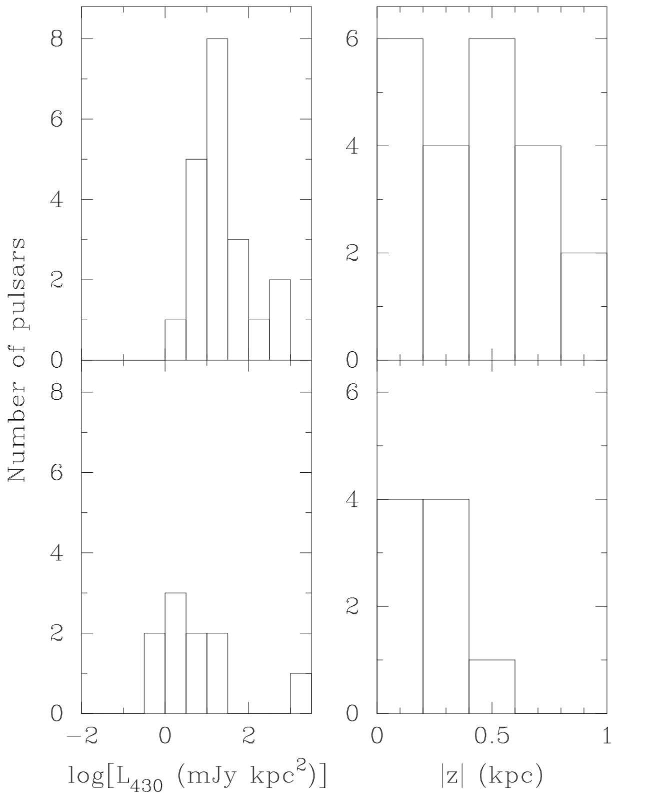

Figure 3. A comparison of the luminosity (left) and $|z|$ distributions (right) for the sample of 32 Galactic disk millisecond pulsars detected in 430-MHz surveys. The top panels show the distributions for the binary millisecond pulsars, while the lower panels show the distributions for the solitary millisecond pulsars. The samples appear to be statistically distinct from one another.

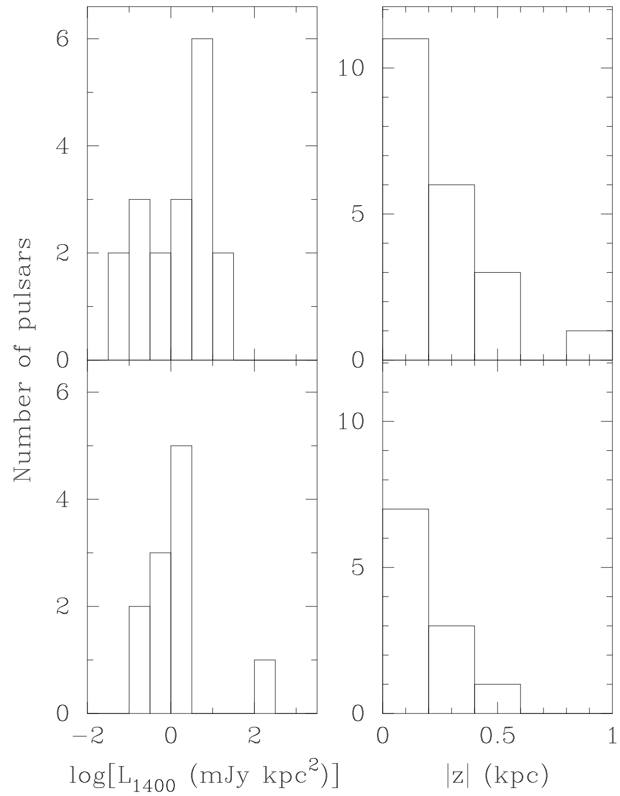

Figure 4. A comparison of the luminosity (left) and z distributions (right) for the sample of 33 millisecond pulsars detected in 1400-MHz surveys. The top panels show the distributions for the binary millisecond pulsars, while the lower panels show the distributions for the solitary millisecond pulsars. The samples are statistically indistinguishable.

tem PSR B1257+12 from this sample, as it may have a separate origin (Banit et al. 1993). The data are summarized in Tables 2 and 3.

Using the Kolmogorov-Smirnoff (KS) statistical test (see, e.g., Press et al. 1986), we have compared the samples of isolated and binary millisecond pulsars in terms of their period, luminosity, spectral index, transverse speed and spin-down luminosity. The only apparently statistically significant difference that we found between the samples was in the luminosity distributions. We now discuss this issue in detail.

Most of the sky has now been searched for millisecond pulsars at both 430 MHz and 1400 MHz. Given that surveys carried out at these two frequencies probe different volumes of the Galaxy, we first wish to assess whether the difference in luminosities is present in the samples of pulsars detected at each frequency. Fig. 3 shows the luminosity and z distributions for the sample of 32 Galactic disk pulsars detected by 430-MHz surveys (10 isolated pulsars versus 22 binary pulsars). From a KS test, we see that the luminosity distributions are different at an apparently statistically significant level of 99.1%. The z distributions appear to be only marginally different, with a KS test returning an 81.3% significance level.

A different conclusion is reached, however, from Fig. 4 which shows the luminosity and $|z|$ distributions for the sample of 33 pulsars detected by 1400-MHz surveys (11 isolated pulsars versus 22 binary pulsars). To the eye, the distributions appear consistent. Indeed, the KS tests also show no statistically significant differences, with the confidence levels for L and z being only 70.9% and 21.1% respectively.

There are two possible explanations as to why the luminosity difference is not seen in both the 430-MHz and 1400-MHz samples. The first possibility is that the high-frequency sample does not probe the luminosity function as deeply as the low-frequency sample. To investigate this, we note that the minimum 1400-MHz luminosity in our sample is 0.1 mJy kpc^2. For a median spectral index of –1.8, the equivalent 430-MHz luminosity is 1 mJy kpc^2. As this limit is slightly higher than the observed 430-MHz distribution in Fig. 3, it remains a tantalyzing possibility that the effect is only seen in the 430-MHz sample which is more slightly more sensitive to the low end of the luminosity function than at 1400 MHz.

A second possibility is that the difference is due to a selection effect. It is well established (see, e.g., Lyne et al. 1998) that 430-MHz surveys probe only the local population of millisecond pulsars out to a distance of 2–3 kpc at most due to propagation effects in the interstellar medium. As a result, samples of pulsars from these surveys tend to be stacked in favour of nearby low-luminosity objects. For any reasonable luminosity function, the high-luminosity pulsars are rarer objects. If isolated millisecond pulsars are simply

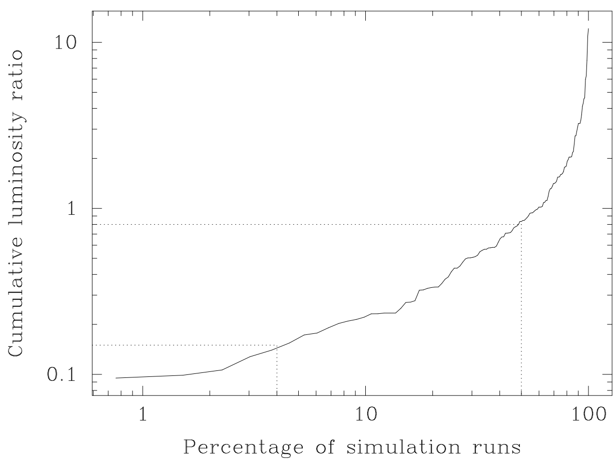

Figure 5. Results of the simulations of samples of millisecond pulsars detectable by a model 430-MHz all-sky survey. For each simulation run, we have computed the ratio of the median luminosities for the 10 object versus 22 object samples and display these as a cumulative distribution plotted against the percentage of all simulation runs. The observed ratio of median luminosities is 0.15 and is shown by the lower dotted line. Such small values were produced in about 4% of all simulation runs. The upper dotted line shows that, in 50% of all cases, the luminosity ratio is less than 0.8.

less numerous than their binary counterparts, small-number statistics will therefore bias the sample in favour of low luminosity objects as there is a greater chance of having a low-luminosity pulsar in the sample compared to a higher luminosity one.

To demonstrate this effect, we have carried out a simple simulation of the millisecond pulsar population using the freely-available PSRPOP software package (Lorimer et al. 2006)[4]. We generated a model galaxy where millisecond pulsars were distributed using the radial distribution proposed by Yusifov & Küçük (2004), an exponential z distribution with a scale height of 500 pc, a 430-MHz luminosity distribution with a slope $d\log N/d\log L = -1$ over the range 0.1–100 mJy kpc^2, the period distribution proposed by Cordes & Chernoff (1997) and intrinsic pulse shapes were approximated as top-hat functions with a duty cycle of 15%. The synthetic pulsars were then 'detected' in the manner as described by Lorimer et al. (2006) using a model all-sky 430-MHz survey with similar sensitivity to the Parkes southern sky survey Lyne et al. (1998). To mimic the statistics shown in Fig. 3, we compared the luminosities of a sample of 10 pulsars randomly selected from our fake all-sky survey and compared this to another larger sample of 22 objects.

Due to the nature of random sampling for these relatively small numbers of objects, we found a considerable variation in the results which are shown as a cumulative distribution in Fig. 5. When averaged over many simulations, the median 430-MHz luminosity of the sample with 10 pulsars was 20% lower than the larger sample, suggesting that this is a significant effect. The observed ratio of the sample medians is $3.4/22.5 = 0.15$. As can be inferred from Fig. 5, such small values were produced in about 4% of all simulations.

[4] `http://psrpop.sourceforge.net`

This simple analysis demonstrates the pitfalls of observational selection and small-number statistics. It appears that the probability of observing apparently different luminosity distributions from identical parent populations is not as small as the KS test would suggest. We note that a recent study of the millisecond pulsar population in globular clusters independently points to similar luminosity functions for isolated and binary millisecond pulsars (Hessels et al. 2007).

5 CONCLUSIONS

We have found the isolated 5.79-ms pulsar J1453+1902 during a 430-MHz drift-scan survey with the Arecibo telescope and measured its spin and astrometric properties in a dedicated timing campaign. This completes the timing of the 11 pulsars discovered in this survey described by Lorimer et al. (2004) and Champion et al. (2005). PSR J1453+1902 appears to be a typical member of the millisecond pulsar population and brings the number of isolated pulsars with periods less than 10 ms currently known in the Galactic disk to 17.

We have revisited the luminosities of isolated and binary millisecond pulsars in the Galactic disk using an up-to-date catalogue of 55 objects. While we confirm an apparently significant difference in the sample of pulsars detected by low-frequency surveys, the effect is not present at all in the sample detected by 1400 MHz surveys. We demonstrate that this could be a selection effect due to isolated millisecond pulsars being intrinsically rare by comparison with the binary millisecond pulsars rather than being intrinsically less luminous.

Based on the currently available data, we suggest that isolated and binary millisecond pulsars have consistent spatial, kinematic and luminosity distributions and there is no longer a need to posit different origins for the two populations. While we can not rule out different origins based on this study alone, we can say, however, that the present data do not *require* the populations of binary and millisecond pulsars to be distinct.

ACKNOWLEDGMENTS

The Arecibo observatory, a facility of the National Astronomy and Ionosphere Centre, is operated by Cornell University in a co-operative agreement with the National Science Foundation. We thank Alex Wolszczan for making the PSPM freely available for use at Arecibo, Michael Kramer for kindly providing the code used in the Lomb-Scargle analysis in Section 3, Andrea Lommen for useful discussions and Matthew Bailes for providing flux density information on PSR J1721−2457.

REFERENCES

Backer D. C., Kulkarni S. R., Heiles C., Davis M. M., Goss W. M., 1982, Nature, 300, 615

Bailes M., Johnston S., Bell J. F., Lorimer D. R., Stappers B. W., Manchester R. N., Lyne A. G., D'Amico N., Gaensler B. M., 1997, ApJ, 481, 386

Banit M., Ruderman M. A., Shaham J., Applegate J. H., 1993, ApJ, 415, 779
Boriakoff V., Buccheri R., Fauci F., Turner K., Davis M. M., 1984, in Reynolds S. P., Stinebring D. R., eds, Birth and Evolution of Neutron Stars: Issues Raised by Millisecond Pulsars National Radio Astronomy Observatory, p. 24
Burgay M., Joshi B. C., D'Amico N., Possenti A., Lyne A. G., Manchester R. N., McLaughlin M. A., Kramer M., Camilo F., Freire P. C. C., 2006, MNRAS, 368, 283
Camilo F., 1995, PhD thesis, Princeton University
Camilo F., Nice D. J., Taylor J. H., 1996, ApJ, 461, 812
Camilo F., Rasio F. A., 2005, in Rasio & Stairs (2005), p. 147
Champion D. J., Lorimer D. R., McLaughlin M. A., Xilouris K. M., Arzoumanian Z., Freire P. C. C., Lommen A. N., Cordes J. M., Camilo F., 2005, MNRAS, 363, 929
Cordes J. M., Chernoff D. F., 1997, ApJ, 482, 971
Cordes J. M., Lazio T. J. W., 2002
Foster R. S., Fairhead L., Backer D. C., 1991, ApJ, 378, 687
Freire P. C., Camilo F., Kramer M., Lorimer D. R., Lyne A. G., Manchester R. N., D'Amico N., 2003, MNRAS, 340, 1359
Fruchter A. S., Berman G., Bower G., Convery M., Goss W. M., Hankins T. H., Klein J. R., Nice D. J., Ryba M. F., Stinebring D. R., Taylor J. H., Thorsett S. E., Weisberg J. M., 1990, ApJ, 351, 642
Hessels J. W. T., Ransom S. M., Stairs I. H., Kaspi V. M., Freire P. C. C., 2007, ApJ
Hobbs G., Faulkner A., Stairs I. H., Camilo F., Manchester R. N., Lyne A. G., Kramer M., D'Amico N., Kaspi V. M., Possenti A., McLaughlin M. A., Lorimer D. R., Burgay M., Joshi B. C., Crawford F., 2004, MNRAS, 352, 1439
Hobbs G., Lorimer D. R., Lyne A. G., Kramer M., 2005, MNRAS, 360, 974
Hobbs G. B., Edwards R. T., Manchester R. N., 2006, MNRAS, 369, 655
Hotan A. W., Bailes M., Ord S. M., 2006, MNRAS, 369, 1502
Jacoby B. A., Bailes M., Ord S. M., Knight H. S., Hotan A. W., 2007, ApJ, 656, 408
Jacoby B. A., Bailes M., van Kerkwijk M. H., Ord S., Hotan A., Kulkarni S. R., Anderson S. B., 2003, ApJ, 599, L99
Jenet F. A., Hobbs G. B., van Straten W., Manchester R. N., Bailes M., Verbiest J. P. W., Edwards R. T., Hotan A. W., Sarkissian J. M., Ord S. M., 2006, ApJ, 653, 1571
Kramer M., Xilouris K. M., Lorimer D. R., Doroshenko O., Jessner A., Wielebinski R., Wolszczan A., Camilo F., 1998, ApJ, 501, 270
Lange C., Camilo F., Wex N., Kramer M., Backer D., Lyne A., Doroshenko O., 2001, MNRAS, 326, 274
Lewandowski W., Wolszczan A., Feiler G., Konacki M., Sołtysiński T., 2004, ApJ, 600, 905
Lommen A. N., Kipphorn R. A., Nice D. J., Splaver E. M., Stairs I. H., Backer D. C., 2006, ApJ
Lommen A. N., Zepka A., Backer D. C., McLaughlin M., Cordes J. M., Arzoumanian Z., Xilouris K., 2000, ApJ, 545, 1007
Lorimer D. R., Camilo F., Xilouris K. M., 2002, ApJ, 123, 1750
Lorimer D. R., Faulkner A. J., Lyne A. G., Manchester R. N., Kramer M., McLaughlin M. A., Hobbs G., Possenti A., Stairs I. H., Camilo F., Burgay M., D'Amico N., Corongiu A., Crawford F., 2006, MNRAS, 372, 777
Lorimer D. R., Kramer M., 2005, Handbook of Pulsar Astronomy. Cambridge University Press
Lorimer D. R., Lyne A. G., Bailes M., Manchester R. N., D'Amico N., Stappers B. W., Johnston S., Camilo F., 1996, MNRAS, 283, 1383
Lorimer D. R., McLaughlin M. A., Arzoumanian Z., Xilouris K. M., Cordes J. M., Lommen A. N., Fruchter A. S., Chandler A. M., Backer D. C., 2004, MNRAS, 347, L21
Lorimer D. R., Nicastro L., Lyne A. G., Bailes M., Manchester R. N., Johnston S., Bell J. F., D'Amico N., Harrison P. A., 1995, ApJ, 439, 933
Lorimer D. R., Xilouris K. M., Fruchter A. S., Stairs I. H., Camilo F., Vazquez A. M., Eder J. A., McLaughlin M. A., Roberts M. S. E., Hessels J. W. T., Ransom S. M., 2005, MNRAS, 359, 1524
Lundgren S. C., Zepka A. F., Cordes J. M., 1995, ApJ, 453, 419
Lyne A. G., Manchester R. N., Lorimer D. R., Bailes M., D'Amico N., Tauris T. M., Johnston S., Bell J. F., Nicastro L., 1998, MNRAS, 295, 743
McLaughlin M. A., Lorimer D. R., Arzoumanian Z. A., Backer D. C., Cordes J. M., Fruchter A. S., Lommen A. N., Xilouris K., 2003, in M. Bailes D. Nice . S. T., ed., Radio Pulsars (ASP Conf. Ser. New pulsars from arecibo drift searches. PASP, San Francisco, pp 129–132
McLaughlin M. A., Lorimer D. R., Champion D. J., Arzoumanian Z., Backer D. C., Cordes J. M., Xilouris K. M., 2005, in Rasio & Stairs (2005), p. 43
Manchester R. N., Lyne A. G., Camilo F., Bell J. F., Kaspi V. M., D'Amico N., McKay N. P. F., Crawford F., Stairs I. H., Possenti A., Morris D. J., Sheppard D. C., 2001, MNRAS, 328, 17
Navarro J., de Bruyn G., Frail D., Kulkarni S. R., Lyne A. G., 1995, ApJ, 455, L55
Nicastro L., Lyne A. G., Lorimer D. R., Harrison P. A., Bailes M., Skidmore B. D., 1995, MNRAS, 273, L68
Nice D. J., Taylor J. H., Fruchter A. S., 1993, ApJ, 402, L49
Ord S. M., van Straten W., Hotan A. W., Bailes M., 2004, MNRAS, 352, 804
Press W. H., Flannery B. P., Teukolsky S. A., Vetterling W. T., 1986, Numerical Recipes: The Art of Scientific Computing. Cambridge University Press, Cambridge
Rasio F., Stairs I. H., eds, 2005, Binary Radio Pulsars Astronomical Society of the Pacific, San Francisco
Shklovskii I. S., 1970, Sov. Astron., 13, 562
Stairs I. H., Faulkner A. J., Lyne A. G., Kramer M., Lorimer D. R., McLaughlin M. A., Manchester R. N., Hobbs G. B., Camilo F., Possenti A., Burgay M., D'Amico N., Freire P. C. C., Gregory P. C., Wex N., 2005, ApJ, 632, 1060
Stappers B. W., Bailes M., Lyne A. G., Manchester R. N., D'Amico N., Tauris T. M., Lorimer D. R., Johnston S., Sandhu J. S., 1996, ApJ, 465, L119
Toscano M., Bailes M., Manchester R., Sandhu J., 1998, ApJ, 506, 863
Wolszczan A., Frail D. A., 1992, Nature, 355, 145

Yusifov I., Küçük I., 2004, A&A, 422, 545

Table 2. The sample of 38 binary millisecond pulsars with $P < 10$ ms currently known in the Galactic disk. From left to right, the columns list pulsar name, spin period (P), binary period (P_b), whether the pulsar was detected in 430-MHz and/or 1400-MHz surveys, the distance (d), height above the Galactic plane (z), flux density at 430 MHz (S_{430}), flux density at 1400 MHz (S_{1400}), spectral index (SI), luminosity at 430 MHz (L_{430}),luminosity at 1400 MHz (L_{1400}) and references to the literature for the quoted distance and flux measurements. Those parameters which have not been measured are denoted by the * symbol.

PSR	P (ms)	P_b (days)	Detected at 430 MHz	Detected at 1400 MHz	d (kpc)	z (kpc)	S_{430} (mJy)	S_{1400} (mJy)	SI	L_{430} (mJy kpc^2)	L_{1400} (mJy kpc^2)	Refs.
J0034−0534	1.877	1.6	yes	no	0.54	−0.50	17	0.61	−2.8	5.0	0.2	1, 2, 2
J0218+4232	2.323	2.0	no	no	2.67	−0.80	35	0.9	−3.1	249.5	6.4	1, 3, 4
J0437−4715	5.757	5.7	yes	yes	0.159	−0.11	550	142	−0.9	13.9	3.6	5, 2, 4
J0610−2100	3.861	0.3	no	yes	3.54	−1.10	*	0.4	*	*	5.0	1, 6
J0613−0200	3.062	1.2	yes	no	0.48	−0.08	21	1.4	−2.3	4.8	0.3	5, 7, 4
J0751+1807	3.479	0.3	yes	no	1.15	0.41	10	3.2	−1.0	13.2	4.2	1, 8, 4
J1012+5307	5.256	0.6	yes	no	0.84	0.65	30	3	−1.9	21.2	2.1	9, 10, 4
J1045−4509	7.474	4.1	yes	yes	1.96	0.42	15	3	−1.4	57.6	11.5	1, 2, 4
J1125−6014	2.630	8.8	no	yes	1.50	0.02	*	0.05	*	*	0.1	1, 11
J1216−6410	3.539	4.0	no	yes	1.33	−0.04	*	0.05	*	*	0.1	1, 11
J1435−6100	9.348	1.4	no	yes	2.16	−0.02	*	0.25	*	*	1.2	1, 12
J1455−3330	7.987	76.2	yes	no	0.53	0.20	9	1.2	−1.7	2.5	0.3	1, 2, 2
J1600−3053	3.598	14.3	no	yes	1.63	0.46	*	3.2	*	*	8.5	1, 13
J1640+2224	3.163	175.5	yes	no	1.16	0.72	*	2	*	*	2.7	1, 4
J1643−1224	4.622	147.0	yes	yes	2.41	0.87	75	4.8	−2.3	435.6	27.9	1, 7, 4
J1709+2313	4.631	22.7	yes	no	1.41	0.75	2.52	0.2	−2.1	5.0	0.4	1, 14, 14
J1713+0747	4.570	67.8	yes	yes	0.91	0.39	36	8	−1.2	29.8	6.6	5, 15, 4
J1732−5049	5.313	5.3	no	yes	1.41	−0.23	*	*	*	*	*	1
J1738+0333	5.850	0.4	no	yes	1.43	0.44	*	*	*	*	*	1
J1741+1351	3.747	16.3	no	yes	0.92	0.34	*	0.93	*	*	0.8	1, 13
J1751−2857	3.915	110.7	no	yes	1.10	−0.02	*	0.06	*	*	0.1	1, 16
J1757−5322	8.870	0.5	no	yes	0.96	−0.23	*	*	*	*	*	1
J1804−2717	9.343	11.1	yes	yes	0.78	−0.04	15	0.4	−3.1	9.1	0.2	1, 2, 4
J1853+1303	4.092	115.7	no	yes	2.09	0.20	*	0.4	*	*	1.7	1, 16
B1855+09	5.362	12.3	yes	yes	1.17	0.06	31	5	−1.5	42.4	6.8	1, 17, 4
J1909−3744	2.947	1.5	no	yes	1.14	−0.38	*	3.0	*	*	3.9	5, 18
J1910+1256	4.984	58.5	no	yes	2.33	0.07	*	0.5	*	*	2.7	1, 16
J1911−1114	3.626	2.7	yes	no	1.22	−0.20	31	0.5	−3.5	46.1	0.7	1, 19, 4
J1918−0642	7.646	10.9	no	yes	1.24	−0.20	*	*	*	*	*	1
J1933−6211	3.354	12.8	no	yes	0.52	−0.25	*	2.3	*	*	0.6	1, 13
B1953+29	6.133	117.3	yes	no	4.64	0.04	15	1.1	−2.2	322.9	23.7	1, 20, 4
B1957+20	1.607	0.4	yes	no	2.49	−0.20	20	0.4	−3.3	124.0	2.5	1, 21, 4
J2019+2425	3.935	76.5	yes	no	1.49	−0.17	2.7	*	*	6.0	*	1, 22
J2033+17	5.949	56.3	yes	no	2.00	−0.45	*	*	*	*	*	1
J2051−0827	4.509	0.1	yes	no	1.04	−0.53	22	2.8	−1.7	23.8	3.0	1, 23, 4
J2129−5721	3.726	6.6	yes	no	1.36	−0.94	14	1.4	−1.9	25.9	2.6	1, 2, 4
J2229+2643	2.978	93.0	yes	no	1.45	−0.64	13	0.9	−2.3	27.3	1.9	1, 15, 4
J2317+1439	3.445	2.5	yes	no	0.83	−0.56	19	4	−1.2	13.1	2.8	1, 24, 4

The references used in this compilation are 1: Cordes & Lazio (2002), 2: Toscano et al. (1998), 3: Navarro et al. (1995), 4: Kramer et al. (1998), 5: Hotan et al. (2006), 6: Burgay et al. (2006), 7: Lorimer et al. (1995), 8: Lundgren et al. (1995), 9: Lange et al. (2001), 10: Nicastro et al. (1995), 11: Lorimer et al. (2006), 12: Manchester et al. (2001), 13: Jacoby et al. (2007), 14: Lewandowski et al. (2004), 15: Camilo (1995), 16: Stairs et al. (2005), 17: Foster et al. (1991), 18: Jacoby et al. (2003), 19: Lorimer et al. (1996), 20: Boriakoff et al. (1984), 21: Fruchter et al. (1990), 22: Nice et al. (1993), 23: Stappers et al. (1996), 24: Camilo et al. (1996).

Table 3. The sample of 17 solitary millisecond pulsars with $P < 10$ ms currently known in the Galactic disk. From left to right, the columns list pulsar name, spin period (P), whether the pulsar was detected in 430-MHz and/or 1400-MHz surveys, the distance (d), height above the Galactic plane (z), flux density at 430 MHz (S_{430}), flux density at 1400 MHz (S_{1400}), spectral index (SI), luminosity at 430 MHz (L_{430}),luminosity at 1400 MHz (L_{1400}) and references to the literature for the quoted distance and flux measurements. Those parameters which have not been measured are denoted by the * symbol.

PSR	P (ms)	Detected at 430 MHz	Detected at 1400 MHz	d	z (kpc)	S_{430} (kpc)	S_{1400} (mJy)	SI (mJy)	L_{430}	L_{1400} (mJy kpc^2)	Refs.
J0030+0451	4.865	yes	no	0.30	−0.25	7.9	0.6	−2.2	0.7	0.1	1, 2, 2
J0711−6830	5.491	yes	yes	0.86	−0.34	10	1.6	−1.6	7.4	1.2	3, 4, 5
J1024−0719	5.162	yes	yes	0.52	0.34	4.6	0.66	−1.6	1.2	0.2	6, 4, 5
J1453+1902	5.793	yes	no	1.15	1.00	2.2	*	*	2.9	*	3, 7
J1629−6902	6.001	no	yes	0.96	−0.23	*	2.7	*	*	2.5	3, 8
J1721−2457	3.497	no	yes	1.29	0.15	*	1.8	*	*	3.0	3, 9
J1730−2304	8.123	yes	yes	0.53	0.06	43	4	−1.9	12.1	1.1	3, 10, 5
J1744−1134	4.075	yes	yes	0.47	0.07	18	3	−1.5	4.0	0.7	6, 11, 5
J1801−1417	3.625	no	yes	1.52	0.11	*	0.17	*	*	0.4	3, 12
J1843−1113	1.846	no	yes	1.69	−0.10	*	0.10	*	*	0.3	3, 13
J1905+0400	3.784	no	yes	1.71	−0.04	*	0.050	*	*	0.1	3, 13
J1911+1347	4.626	no	yes	2.07	0.07	*	0.08	*	*	0.3	3, 12
B1937+21	1.558	yes	yes	3.57	−0.02	240	10	−2.7	3058.8	127.4	3, 14, 5
J1944+0907	5.185	yes	no	1.79	−0.23	3.9	*	*	12.5	*	3, 15
J2010−1323	5.223	no	yes	1.02	−0.41	*	1.6	*	*	1.7	3, 16
J2124−3358	4.931	yes	no	0.25	−0.18	17	1.6	−2.0	1.1	0.1	6, 11, 5
J2322+2057	4.808	yes	no	0.80	−0.48	0.5	*	*	0.3	*	3, 17

The references used in this compilation are 1: Lommen et al. (2006), 2: Lommen et al. (2000), 3: Cordes & Lazio (2002), 4: Bailes et al. (1997), 5: Kramer et al. (1998), 6: Hotan et al. (2006), 7: this paper, 8: Ord et al. (2004), 9: Bailes (2007) private communication, 10: Lorimer et al. (1995), 11: Toscano et al. (1998), 12: Lorimer et al. (2006), 13: Hobbs et al. (2004), 14: Foster et al. (1991), 15: Champion et al. (2005), 16: Jacoby et al. (2007), 17: Nice et al. (1993).